Personality, Chrono-nutrition and Cardiometabolic Health: A Narrative Review of the Evidence

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ABSTRACT

Growing evidence suggests that personality traits play a role in obesity and cardiometabolic health. In addition, irregularity of food intake has emerged as a potential risk factor for obesity, cardiovascular disease, and metabolic syndrome. Recent studies suggest that when we eat, termed "chrono-nutrition," may be as important to what we eat. This concept covers 3 aspects: *1*) irregularity of energy intake in meals (varying amounts of energy intake throughout the day and at different times from one day to the next), *2*) frequency (number of meals per day), and *3*) timing of food intake (actual time of day). A narrative review was conducted to identify literature evaluating the effect of personality on chrono-nutrition and subsequently obesity and cardiometabolic health. The search focused on research published since 2000 in MEDLINE using the search terms "personality," "chrono-nutrition," "cardiometabolic," "BMI," "obesity," and "metabolic rate." Findings indicate an inverse relation between conscientiousness and obesity, with people who are more conscientious having a lower risk of obesity. Furthermore, time of day of energy intake has been linked to obesity, since meals consumed in the evening have been associated with lower resting metabolic rate. Inconsistent timing and frequency of meals have also been linked to increased body weight and worse cardiometabolic health. Together, the data indicate that eating meals at the same time every day at regular intervals might be the reason why those who score high in conscientiousness are able to maintain a healthier weight. Despite the reviewed observational evidence, there is an apparent gap in the existing literature on the interplay between personality, chrono-nutrition, and obesity and particularly on how dietary interventions should be designed considering different personality traits. Future research is needed to clarify this association and how it interacts with other factors, thus elucidating the role of chrono-nutrition in health. *Adv Nutr* 2020;11:1201–1210.

Keywords: personality, chrono-nutrition, cardiometabolic health, BMI, obesity

Introduction

Growing evidence suggests that, in addition to genetic, environmental, and social factors influencing the risk of obesity, personality and individual differences in the way people think, behave, and feel may also play a role (1). One of the best-known, widely used, reliable, and valid measures of personality is the Five Factor Model (FFM) or Big Five, which captures personality in dimensions of Neuroticism, Extraversion, Openness to experience, Conscientiousness, and Agreeableness (2). These 5 replicable, broad dimensions of personality characterize individuals in terms of universal patterns of thoughts, feelings, and actions (2). Used frequently in research, the FFM has independent dimensions with evidence for external validity when compared with other measures of personality (2). Neuroticism is characterized by being active, optimistic, and assertive; extraversion by being enthusiastic and action oriented; openness by being curious, imaginative, and open-minded; conscientiousness by being strong-willed, orderly, and self-disciplined; and agreeableness by compliance and sympathy (3). A number of studies suggest that personality traits such as neuroticism, extraversion, openness, and agreeableness are associated with a BMI (4–6), while other studies have consistently shown that a high level of conscientiousness is associated with a lower risk of obesity (1, 7, 8).

Since the basic personality traits people are born with are consistent and stable over time (9), the effect of personality on dietary intake is of interest. Certain personality traits such as conscientiousness are associated with consistent behaviors—for example, having a meal at similar times of the day and compliance to healthy behavior (9). The eating

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Abbreviations used: FFM, Five Factor Model; RMR, resting metabolic rate; T2D, type 2 diabetes; TEF, thermic effect of food; TG, triglyceride.

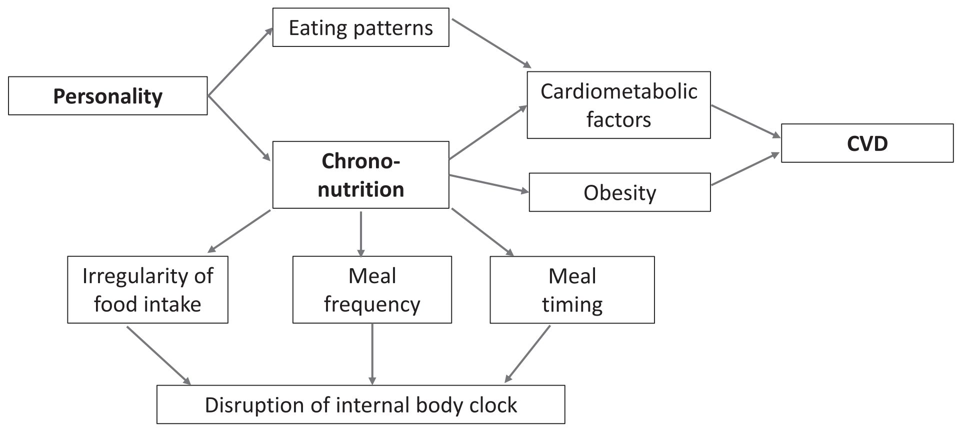

FIGURE 1 Relations between personality and cardiometabolic health outcomes. CVD, cardiovascular disease.

habit of interest in this review is the concept of "chrono-nutrition," focusing not just on what we eat but also when we eat (10), which might be indirectly related to personality. Chrono-nutrition refers to coordinating food intake with the circadian body rhythm (i.e., the internal biological clock) (11). It covers 3 aspects, as follows: *1*) irregularity of food intake (varying amounts of energy intake throughout the day and at different times from one day to the next), *2*) frequency of food intake (number of meals per day), and *3*) timing of food intake (actual time of day) (12, 13). Current theories on the topic suggest an association between meal patterns and timings with weight, which may be caused by a physiological adaptation to sleeping and eating at abnormal circadian times (10). Consuming irregular meals may affect the circadian body rhythm including many physiological and metabolic-related processes, such as glycolysis, glycogenesis, and lipid metabolism (10). Furthermore, circadian misalignment has been shown to cause changes in concentrations of circulating satiety hormones, such as leptin and ghrelin, with subsequent effects on energy intake and expenditure (14). The thermic effect of food (TEF) (i.e., the increase in energy expenditure after meal consumption) is also important to consider. The TEF has been shown to be significantly higher after consumption of a snack in the morning versus at night (15). Furthermore, this reduced evening thermic response may be linked to nocturnal insulin resistance (15), thus showing a link between the timing of meals and TEF.

Indeed, the role of meal patterns and timings is a subject of debate in weight management (16–18), especially considering emerging evidence showing that intermittent fasting may be an effective method for weight loss (19, 20). Most weight-loss interventions, however, focus only on energy restriction (21–23) rather than chrono-nutrition (i.e., meal timing).

Interest in the area of chrono-nutrition and health is growing as evidenced by several recently published reviews. Nevertheless, none of these have attempted to link together personality, chrono-nutrition, and cardiometabolic health. Although this present review complements results of previous reviews (11, 13) that gave an overview of chrono-nutrition and its implications on cardiometabolic health and obesity, no reviews have addressed personality. The current literature, for example, has linked chrono-nutrition to sleep and cardiometabolic disease, with the former possibly having a mediating effect (18, 24). On the other hand, a systematic review on personality traits and obesity concluded that conscientiousness was protective against weight gain, but it did not address chrono-nutrition (8). The present review is thus the first to attempt to disentangle the evidence on all 3 aspects—namely, personality, chrono-nutrition, and cardiometabolic health—as suggested in **Figure 1**.

Considering this background, the review aims to *1*) provide an overview of the current literature on the association between personality and eating patterns, *2*) provide an overview of the current literature on the association between personality and obesity, *3*) provide an overview of recent research on chrono-nutrition in relation to obesity and cardiometabolic health, and *4*) present current research on personality and its association to chrono-nutrition and cardiometabolic health.

Methods

A narrative review was conducted in MEDLINE via PubMed. The search focused on citations after the year 2000 to capture the most recent evidence. The following combinations of keywords were used as search terms: "personality," "chrono-nutrition," "cardiometabolic," "BMI," "obesity," and "metabolic rate." Inclusion criteria were studies published in English and conducted in adults (aged >18 y). The reference lists of the articles retrieved were also screened for any relevant articles, resulting in 26 eligible studies.

Results

Tables 1–4 provide a summary of the characteristics and main findings of the included studies, which are also discussed below.

Personality and eating patterns

Personality traits were shown to be strongly correlated with eating styles and personal food choices (1, 3–6, 25–27). As a result, certain personality traits may be risk factors for

TABLE 1 Summary of studies on personality and eating patterns[1]

Study (reference)	Study design	Study duration	Sample size, n	Age, y	Main findings
Kituchi and Watanabe, 2000 (26)	Longitudinal study	2 y	470	19.8–21.8	Food intake influenced by personality. Examples include: High scores of C associated with frequent consumption of green/yellow vegetables (OR = 4.88, 95% CI = 1.28–18.57 for males; OR = 2.69, 95% CI = 1.39–5.21 for females). N had taste preferences for sweet (OR = 21.00 [2.40–183.99] in males; OR = 3.33 [1.61–6.91] in females) and salty (OR: 2.39; 1.16–4.93) in females only.
Keller and Siegrist, 2015 (3)	Cross-sectional study	N/A	951	20–79	C had a significant positive indirect effect on fruit consumption (SDI = 0.024; 95% CI: 0.006, 0.038). N had a significant positive indirect effect on sweet and savory food consumption (SDI = 0.067; 95% CI: 0.029, 0.095) as well as E (SDI = 0.025; 95% CI: 0.014, 0.041), whereas C had a significant negative indirect effect (SDI = −0.045, 95% CI: −0.058, −0.027). E had a significant positive indirect effect on meat consumption (SDI = 0.015; 95% CI: 0.007, 0.029) and C had a significant negative indirect effect (SDI = −0.014; 95% CI: −0.024, −0.002). E had a significant positive indirect effect (SDI = 0.016; 95% CI: 0.005, 0.026) and C had a significant negative indirect effect (SDI = −0.034; 95% CI: −0.048, −0.015) on sweetened-drink consumption.
Raynor and Levine, 2009 (25)	Cross-sectional study	N/A	583	College students	C and O more likely to consume F/V ($\beta = 0.16$ and $\beta = 0.14$ respectively; $P < 0.01$).
Reeves et al., 2013 (48)	Cross-sectional study	5 d	1066	>18	Breakfast frequency correlated with C (Spearman's ρ: 0.12; $P < 0.001$).
Vainik et al., 2015 (49)	Cross-sectional study	19 d	164	18–75 (women)	Eating consistently associated with self-control (C) (factor loading: 0.80).

[1]C, conscientiousness; E, extraversion; F/V, fruit and vegetables; O, openness; N, neuroticism; N/A, ; SDI, standardized indirect effect.

an unbalanced diet and chronic diseases such as CVD and type 2 diabetes (T2D). A cross-sectional study conducted in Switzerland in 951 adults aged 20–79 y was the first to demonstrate that personality indirectly influences food consumption. Key findings suggested that conscientiousness had a significant negative indirect effect on consumption of an unbalanced diet (3) and neuroticism had a significant positive indirect effect on sweet and savory food consumption (3). Similar studies have also reported that neuroticism was positively correlated with emotional eating, external eating (eating in response to food cues), consumption of sweet and savory foods, as well as susceptibility to hunger (5, 25). Sutin and Terracciano's review (4) suggested an association between neuroticism and disordered eating, whereas openness and extraversion were associated with consumption of healthier diets. Conscientiousness was positively associated with higher cognitive dietary restraint and fruit and vegetable consumption and was negatively associated with emotional and external eating (5, 25). Other studies have associated high conscientiousness with avoidance of salty foods and a higher probability of consumption of yellow and green vegetables (1, 26). Highly conscientious individuals practice dietary restraint and regulation of emotional or external eating, resulting in consuming more of the recommended foods compared with those with other personality traits. In fact, a cross-sectional study in 154 women in Quebec (5) found that conscientiousness was positively associated with dietary restraint and control of food intake, and agreeableness predicted a lower susceptibility to hunger. However, the study was limited because all participants were women preoccupied with their weight. Some evidence also suggests that those scoring high in conscientiousness consume breakfast regularly (27), tend not to snack, and consume their meals at regular times each day (6, 27). A number of studies have associated low conscientiousness with unhealthy eating patterns (1, 4–6).

Personality and obesity

The reviewed evidence indicates that conscientiousness is the trait most consistently negatively associated with BMI and obesity in multiple populations and using different questionnaire measures of personality (1, 4–9, 28–31). Since highly conscientious individuals are typically more organized and self-disciplined, they are more likely to follow a healthy diet and engage in health behaviors in general, compared with other personality traits (1, 4, 6). This association found

TABLE 4 Summary of intervention studies on obesity, cardiometabolic health, and chrono-nutrition[1]

Study (reference)	Study design	Methods	Study duration	Sample size, n	Age, y	Main findings
Bo et al., 2015 (15)	Randomized crossover trial	Random consumption of a standard meal in the morning or evening, or vice versa	7 d	20	20–35	After meal RMR was higher after morning meal (1916; 95% CI = 1792, 2041 kcal vs 1756; 95% CI: 1648, 863 kcal; $P < 0.001$). Differences in AUCs for glucose (−1800; −2564, −1036 mg $dL^{-1} \times h$; $P < 0.001$), log-insulin (−0.19; −0.30, −0.07 $\mu U\ mL^{-1} \times h$; $P = 0.001$) and free fatty acid concentrations (−16.1; −30.0, −2.09 mmol $L^{-1} \times h$; $P = 0.024$) were significantly lower after morning vs evening meal.
Byrne et al., 2018 (20)	Randomized controlled trial	Randomly assigned to 16 wk of either *1*) CON or *2*) INT ER completed as 8 × 2-wk blocks of ER alternating with 7 × 2-wk blocks of energy balance (30 wk total)	16 wk	47	28–54 (men)	Greater weight loss (14.1 ± 5.6 vs 9.1 ± 2.9 kg; $P < 0.001$) and greater fat mass loss (12.3 ± 4.8 vs 8.0 ± 4.2 kg; $P < 0.01$) for INT group vs CON group.
Chowdhury et al., 2018 (35)	Randomized controlled trial	Consumption of either ≥700 kcal of self-selected items before 11:00 h or fasting (0 kcal) until 12:00 h daily Metabolic and appetite responses to a standardized breakfast and ad libitum lunch before and after the intervention were examined	6 wk	31	22–56	No differences between groups in total and acylated ghrelin, leptin, and peptide tyrosine-tyrosine. Ad libitum energy intake at lunch not systematically affected by either intervention. Glycemic, insulinemic, lipemic, and thermogenic responses to breakfast and lunch did not differ between treatment groups.
Farshchi et al., 2004 (41)	Randomized crossover trial	Consumption of normal diet on either 6 occasions per day (regular) or by following a variable meal frequency (3–9 meals/d, irregular) and crossover after 2 wk washout	14 d	9	18–42 (women)	The irregular meal pattern was associated with higher fasting total (pre vs post diet: 3.56 ± 0.60 vs 3.82 ± 0.66 mmol/L; $P < 0.01$) and LDL (pre vs post diet: 1.98 ± 0.14 vs 2.10 ± 0.40 mmol/L; $P < 0.01$) cholesterol compared with regular meal pattern.
Farshchi et al., 2005 (34)	Randomized controlled trial	Same as Farshchi et al 2004 (41)	28 d	10	32–47	Regular eaters were associated with lower EI (7.98 ± 0.49 MJ/d vs 8.32 ± 0.35 MJ/d), greater postprandial thermogenesis ($P = 0.002$), and lower total cholesterol (pre vs post diet: 4.27 ± 0.52 vs 4.29 ± 0.52 mmol/L) and LDL (pre vs post diet: 2.57 ± 0.61 vs 2.60 ± 0.70 mmol/L) vs irregular meal eaters (all $P < 0.01$).

(*Continued*)

TABLE 4 (*Continued*)

Study (reference)	Study design	Methods	Study duration	Sample size, *n*	Age, y	Main findings
Garaulet and Gómez-Abellán, 2013 (14)	Intervention study	Weight-loss program	20 wk	420	31–35 (women)	Late lunch eaters lost less weight than early lunch eaters (% weight loss: 9.0 ± 7.1 kg vs 11.3 ± 5.8 kg; $P = 0.006$).
Nguyen and Wright 2010 (40)	Intervention study	Following a 3-wk, ∼8 h per night home sleep schedule, participants were scheduled to either 24.0 or 24.6 h of wakefulness-sleep schedules for 25 days.	25 d	14	25.7–37.5	Circadian misalignment resulted in reduced leptin concentrations. AUC and average leptin concentrations were significantly reduced by 10% during scheduled wakefulness in the misaligned group ($P < 0.05$).
Sheer et al., 2009 (38)	Intervention study	Subjects ate and slept at all phases of the circadian cycle, achieved by scheduling a recurring 28-h "day"; subjects ate 4 isocaloric meals each 28-h "day"	10 d	10	19–41	Circadian misalignment resulted in increase in postprandial glucose (+6%, $P < 0.001$), insulin (+22%, $P = 0.006$), and blood pressure (+3%, $P = 0.001$).

[1]CON, continuous; EI, energy intake; ER, energy restriction; INT, intermittent; RMR, resting metabolic rate.

TABLE 2 Summary of studies on personality and obesity[1]

Study (reference)	Study design	Study duration, y	Sample size, *n*	Age, y	Main findings
Brummett et al., 2006 (31)	Longitudinal study	14	3401	39–49	Predictors of linear change in BMI during midlife: Age × personality β (P value): N = 0.001 (0.744), E = −0.005 (0.316), O = 0.010 (0.070), A = 0.003 (0.465), C = −0.010 (0.037)
Provencher et al., 2008 (5)	Randomized cross-sectional study	4	154	36.8–48.0	Positive association between C and BMI ($r = 0.20$, $P = 0.01$)
Sutin et al., 2011 (1)	Longitudinal study	1	1988	50	Partial correlations controlling for sex, age, age-squared, ethnicity, and education between personality and BMI: N: $r = 0.07$, $P < 0.001$; E: 0.09, $P < 0.001$; C: −0.06, $P < 0.001$.
Sutin and Terracciano, 2016 (27)	Cross-sectional study	N/A	5150	>18	N associated with higher BMI (OR: 1.23; 1.15–1.31; $P < 0.01$); C associated with lower BMI (−0.79; 0.74–0.84; $P < 0.01$)
Terracciano et al., 2009 (6)	Longitudinal study	6	5693	14–94	Impulsiveness associated with overweight and obese vs normal (OR: 1.036; 95% CI: 1.026, 1.046; $P < 0.001$). Prospective analysis showed that those scoring in the top 10% of Impulsiveness were ∼4 kg heavier than those scoring in the lower 10% of the distribution 3 y later.
Wimmelmann et al., 2018 (28)	Cross-sectional study	N/A	5286	49–63	Associations between personality traits and obesity in men and women High vs low E = OR: 1.2 (95% CI: 0.8, 1.8), $P = 0.062$ in women; 1.4 (1.1, 1.8), $P \le 0.039$ in men High vs low A = OR: 0.7 (95% CI: 0.5, 1.0; $P = 0.026$) in women; 0.9 (0.7, 1.1; $P = 0.436$) in men High vs low 0 = OR: 0.7 (95% CI: 0.5, 1.0; $P = 0.037$) in women; 0.9 (0.7, 1.1; $P = 0.540$) in men High vs low C = OR: 0.7 (95% CI: 0.5, 1.1; $P = 0.176$) in women; 0.8 (0.6, 1.0; $P = 0.059$) in men High vs low N = OR: 0.9 (95% CI: 0.6, 1.4; $P = 0.586$) in women; 1.1 (0.8, 1.4; $P = 0.811$) in men

[1] A, agreeableness; C, conscientiousness; E, extraversion; O, openness; N, neuroticism.

in most of the literature tends to be similar across age groups (1, 29) but is not consistent for both sexes. For example, a recent cross-sectional study in 5286 Danish adults found that all personality traits except for neuroticism were significantly associated with BMI, with conscientiousness being negatively associated with BMI only in men (28). Other studies, however, found that the negative association was stronger for women (30). Findings with regard to sex are also not consistent for extraversion, since a negative association between this trait and BMI was found in women only in 1 study (4), whereas another study found no association in either sex (31).

Personality is not only a predictor of BMI and change in weight but also of the risk of developing obesity over time. In a longitudinal study in 1988 individuals aged 50 y old, it was shown that those scoring high on neuroticism or low in conscientiousness had a higher BMI and more weight fluctuations (1). Individuals with the facets of these traits related to impulsivity and low self-discipline may find it more difficult to commit to healthy diets, restrained eating, and regular physical activity, which are typically necessary to maintain a healthy weight (1). It is of note, however, that the college-educated sample of the study is not representative of the general population and therefore findings may not be generalizable. Nevertheless, this association between personality and BMI has been observed in various countries, suggesting that it is not age or culturally dependent. A similar association between low scores of conscientiousness and high BMI (6) was found in a large longitudinal study in 5693 persons in Sardinia, Italy. This is important since the Sardinian population tends to have lower rates of obesity and maintains a healthier Mediterranean diet compared with the US samples (29).

The associations between the other remaining personality traits and obesity are less consistent. Agreeableness, neuroticism, and extraversion have been associated with an increased risk of obesity (5, 31), while other research has linked impulsiveness to being overweight and obese (6). Although some evidence suggests that higher extraversion is associated with a higher BMI (8), this is not confirmed in other research (6). Contradictory findings are also present for openness and BMI, with 1 study finding no associations and another study demonstrating that those scoring high in openness had a lower BMI (31). This inconsistency in results could be related to study sample bias, since research participants may be more conscientious than nonparticipants (9).

TABLE 3 Summary of observational studies on obesity, cardiometabolic health and chrono-nutrition[1]

Study (reference)	Study design	Study duration	Sample size, *n*	Age, y	Main findings
Kahleova et al., 2017 (17)	Longitudinal study	7 y	50,660	≥30	Consuming vs skipping breakfast (−0.029; 95% CI: −0.047, −0.012; *P*-trend < 0.001) and largest meal in morning vs dinner (−0.038; 95% CI: −0.048, −0.028; *P* <0 .001) associated with lower BMI.
Ma et al., 2003 (33)	Cross-sectional study	4 y	499	20–70	Greater number of eating episodes each day associated with a lower risk of obesity (OR for ≥4 eating episodes vs ≤3 episodes: 0.55; 95% CI: 0.33, 0.91). Skipping breakfast associated with increased prevalence of obesity (OR = 4.5; 95% CI: 1.57, 12.90).
Pot et al., 2014 (12)	Longitudinal study	53 y	1786	53	An increased risk of the metabolic syndrome was associated with more irregular energy intake during breakfast (OR: 1.34; 95% CI: 0.99, 1.81; *P*-trend = 0.04) and between meals (OR: 1.36; 1.01, 1.85; *P*-trend = 0.04).
Pot et al., 2016 (42)	Longitudinal study	43 y	1786	36 and 43	At age 36 y, subjects with a more irregular intake of energy at lunch (OR: 1.42; 95% CI: 1.05, 1.91) and between meals (OR: 1.35; 95% CI: 1.01, 1.82) had an increased risk of metabolic syndrome 17 y later. At age 43 y, subjects with a more irregular intake at breakfast had an increased risk of the metabolic syndrome 10 y later (OR: 1.53; 95% CI: 1.15, 2.04) and increased BMI (OR: 1.66; 95% CI: 1.31, 2.10).
Reid et al., 2014 (36)	Cross-sectional study	7 d	59	19.2–42.8	Eating frequency (0.44; *P* < 0.001), last time of meal (0.39; *P* < 0.81), duration between last meal and sleep onset (0.36; *P* < 0.001), and duration between dinner and last meal (0.32; *P* < 0.05) were associated with total caloric intake.
Wang et al., 2014 (16)	Cross-sectional study	3 y	326	21–69	Eating more of total intake at midday vs eating more of total intake in evening associated with lower risk of being obese (OR: 2.00; 95% CI: 1.03, 3.89; *P* < 0.01).
Zhang et al., 2018 (43)	Cross-sectional study	3 mo	2290	29–74	EF not associated with obesity.

[1]EF, eating frequency.

Chrono-nutrition in relation to obesity and cardiometabolic health

Emerging evidence suggests that the timing of food intake is linked to cardiometabolic disease, a cluster of metabolic abnormalities related to obesity, diabetes, and cardiovascular disease (10, 12, 14–16, 20, 24, 32–42). In particular, regular meal consumption has been associated with a decreased risk of metabolic syndrome (10, 15) and better weight outcomes (14). The time of day at which people eat has also been associated with weight outcomes (14).

Of the studies investigating meal timing in humans, the majority found that breakfast consumption is associated with a reduced risk of obesity (33–36). In particular, consumption of a high caloric intake during breakfast was associated with significantly more weight loss compared with consumption of a high caloric intake during dinner (36). Recent reviews have suggested that people who consume breakfast daily may have a reduced risk of abnormalities in glucose and insulin metabolism (24).

Associations between late-evening food consumption and higher BMI have also been demonstrated in observational studies (37). Evidence suggests that individuals who undertook night eating, either with the majority of energy intake in the evening or close to sleep onset (start of sleep), tended to have a higher BMI (36). Eating late in the day was also associated with less weight loss than eating early in the day (14). In an extreme example (i.e., that of nightshift work), the disruption in circadian rhythm increases the risk of obesity and diabetes (38). This is exacerbated by a more irregular eating pattern, altered meal frequency, and irregular distribution of dietary intake throughout the day (39). Energy homeostasis is affected by circadian rhythms of wakefulness and sleep. Even a few weeks of circadian misalignment, caused by eating and sleeping >12 h out of the habitual time phase, resulted in altered leptin concentrations, increased glucose and insulin concentrations, and appetite and energy imbalance (38, 40). In addition, circadian misalignment caused increases in mean arterial pressure and postprandial glucose responses typical of a prediabetic state (38), highlighting its importance for healthy cardiometabolism. Indeed, recent human studies suggest that earlier meal timing compared with late eating is associated with improved effectiveness of weight-loss therapy in overweight and obese patients (14). A recent study in obese women found that regular meal consumption for 2 wk resulted in beneficial effects on cardiometabolic risk factors (34). Meal frequency, which is another aspect of chrono-nutrition, is also relevant since a higher risk of being overweight or obese has been observed with eating $\geq$5 meals/d compared with eating $\leq$3 meals/d (41).

Evidence also suggests that individuals with a more irregular intake especially at breakfast, lunch, and between meals have an increased risk of metabolic syndrome (10, 34), thus highlighting the importance of regular meal patterns for carbohydrate and lipid metabolism. Regular eating patterns were associated with lower energy intake, greater postprandial thermogenesis, and lower fasting total and LDL cholesterol (38). Furthermore, regular eating patterns can reduce the risk of obesity and chronic diseases through mechanisms involved in energy balance and metabolism, including satiety (20). A cross-sectional study in 1768 participants in the Medical Research Council's National Survey of Health and Development in the United Kingdom associated meal regularity using data from 5-d food diaries with the risk of metabolic syndrome (12). The study found that those who consumed a more irregular energy intake during breakfast, as well as between meals, had an increased risk of metabolic syndrome and had a higher waist circumference and BMI. No significant associations were found for other components of the metabolic syndrome such as blood pressure, plasma HDL cholesterol, and plasma triglyceride (TG) concentrations. This was the first study to investigate meal irregularity by assessing the variability in energy intake in meals from one day to the other. A limitation of this study, however, was the missing data on HDL cholesterol for 366 individuals and assessing TG concentration in nonfasting blood samples. Further research on prospective associations in the same cohort revealed that an irregular intake of energy during breakfast, lunch, and between meals increased the risk of developing metabolic syndrome 17 y later (42). Sample attrition, however, may result in bias since healthier and more health-conscious individuals are more likely to remain in the study.

More evidence on chrono-nutrition and body weight comes from a recent longitudinal study in 50,660 adults (aged $\geq$30 y) taking part in the Seventh Day Adventist Health Survey in Canada and the United States. Consumption of the largest meal at breakfast versus at lunch or dinner was associated with a lower BMI, and breakfast eaters had a lower BMI compared with breakfast skippers (16). Although it is a large-cohort study, it is limited due to self-reported measures of meal frequency and timing, lack of detailed information on amount consumed per meal, and lack of differentiation between intentional and unintentional weight loss.

A recently published cross-sectional study in 2824 adults aged 29–74 y in China found no relation between obesity and eating patterns (43). Obesity was not associated with meal frequency. This contradicts the previously reported research that found associations between chrono-nutrition and obesity. The self-reported data used and the cross-sectional design of this study are limitations, however. The study also defined eating frequency as the reported time of day of eating meals, which differs from other reviewed studies, thus contributing to the inconsistency of the results.

Another aspect of energy expenditure to consider is the TEF, which has also been implicated in obesity. In a recent randomized crossover study, Bo et al. (15) compared calorimetric and metabolic responses to identical meals consisting of high protein and low carbohydrate consumed in the morning with those in the evening in 20 healthy participants. Although there were no changes in the resting metabolic rate (RMR), the TEF was significantly higher after the morning meal than after the evening meal. This possibly reiterates the association of a circadian pattern in thermic and metabolic responses and highlights the importance of meal timing. Another study looking at the thermogenic response to meal patterns found that regular eating was associated with lower energy intake, greater postprandial thermogenesis, and lower circulating lipid concentrations in healthy obese women (34). Limitations of these studies, however, include the underestimation of energy intake in self-reporting, which commonly occurs in obese participants.

Interestingly, the association shown (15) was not replicated in a recently published study (35). Using a parallel-group design, the influence of consuming daily breakfast on metabolism and appetite was examined in 31 healthy, lean participants (35). Participants were randomly assigned to either a fasting group consuming no energy before 12:00 h or a breakfast group consuming $\geq$700 kcal before 11:00 h daily for 6 wk. Metabolic and appetite responses were assessed at baseline and after the intervention. RMR was shown to be similar between fasting and breakfast groups, thus suggesting that morning fasting does not cause detrimental effects on metabolic regulation in lean adults. Furthermore, glycemic and insulinemic responses to breakfast and lunch did not differ between treatment groups. The study, however, did not provide details on breakfast composition other than energy content.

Personality and its association with chrono-nutrition and cardiometabolic health

This review did not find any studies assessing the link between personality and chrono-nutrition and only a few studies addressed the association of personality and cardiometabolic risk (44–47). Out of the 5 main personality traits, neuroticism and agreeableness were associated with the highest risk of metabolic syndrome, while conscientiousness was found to play a protective role (44, 45). People scoring low in conscientiousness were found to have higher concentrations of C-reactive protein, an inflammatory marker linked to chronic disease and risk of T2D (46). A recent cross-sectional study in 856 volunteers participating in the University of Pittsburgh Adult Health and Behavior

Project (AHAB) analyzed the association of personality with cardiometabolic risk (47). Those who scored low in conscientiousness had a higher cardiometabolic risk as evidenced by insulin resistance, dyslipidemia, central adiposity, and elevated blood pressure. This was the first study to use a "well-validated" measure of personality that was completed by multiple investigators instead of relying on self-report personality traits, as in the previously mentioned studies in this review. However, the cross-sectional nature of the study only allows testing associations but cannot prove causality.

Summary of the Evidence on Personality, Chrono-nutrition, and Cardiometabolic Health

In summary, the current review findings indicate that highly conscientious individuals tend to consume meals at regular times each day and are more organized and self-disciplined compared with those with other personality traits. In addition, out of the 5 personality dimensions, conscientiousness seems to be consistently associated with a lower BMI and decreased risk of obesity in various populations. Furthermore, evidence suggests that neuroticism and agreeableness increase the risk of the metabolic syndrome, while conscientiousness is protective.

The reviewed studies did not address chrono-nutrition in relation to personality and cardiometabolic health. However, evidence suggested that regular meal consumption is associated with a reduced risk of the metabolic syndrome.

Limitations in the Reviewed Research

The reviewed research evidence is heterogeneous in the definition of chrono-nutrition. In some studies, dietary assessment was done using predefined meal slots (breakfast, lunch, dinner, between meals) in 5-d food diaries; meal irregularity was defined as the variability in energy intake per meal relative to the 5-d mean of energy intake during that meal (12, 42). In other studies, classification of meal distributions was based on self-defined meal slots (36), whereas 1 study defined meal irregularity as meal frequency (41). This inconsistency in terminology and definitions makes it difficult to assess and compare all of the evidence on this topic. Last, most studies used a participant self-reported approach with regard to meals. Two current published reviews (11, 13) also highlighted the unclear dietary assessment methods used in most of the studies related to chrono-nutrition, which indicates that the relevant concepts are still not well defined. In addition, since the prevalence of cardiometabolic risk factors is not fully established until midlife (49), this may be underrepresented in the reviewed studies since studies included younger populations. Overall, the inconsistencies seen could affect the interpretation and comparison of research results.

Conclusions

A few studies hypothesized that eating meals at the same time every day and at regular intervals might be the reason why those who score high in conscientiousness are able to maintain a healthier weight (6, 21). Although not derived from studies explicitly investigating the interplay between personality, chrono-nutrition, and obesity/cardiometabolic health, there is accumulating evidence in the literature supporting this. In particular, conscientiousness was the trait most strongly related to eating at the same time every day and consuming breakfast daily. Furthermore, those who scored high in conscientiousness were better at keeping their meals consistent, most probably due to self-control and the drive to meet their goals in a planned and organized manner.

In this review, the scarcity of literature on the interplay between personality, chrono-nutrition, and cardiometabolic risk was highlighted. Most of the evidence presented is on the individual association between personality, dietary intake, and cardiometabolic factors without linking these together in a multivariate mediation model (i.e., path analysis). This highlights an important gap in the literature on the effect of personality on chrono-nutrition and, subsequently, on obesity and cardiometabolic risk.

Recommendations

Further studies are needed to investigate the role of meal timing in human weight regulation in relation to personality. While obesity is an established worldwide problem, effective strategies on the prevention and management of obesity are limited. Interventions that control the number of meals and/or when the last meal is consumed may potentially enhance the effectiveness of standard weight-management programs. Although a few studies have suggested that irregular meal consumption is associated with a higher risk of metabolic syndrome and cardiometabolic risk factors including BMI, evidence is still limited. Most of the studies published suggest a link between personality and dietary patterns, without dealing with the interplay between the different factors involved and the relevant health consequences; therefore, further investigation is necessary. We propose that intervention studies should be designed and implemented to tailor weight-loss and cardiometabolic health interventions to personality traits by taking into consideration aspects of chrono-nutrition.

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